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THE COMPOSITION OF SOME ANCIENT BRONZE IN THE DAWN OF THE ART OF METALLURGY

By GEORGE BRINTON PHILLIPS

THE antiquity of bronze is still in doubt. In Babylonia, lance heads of metal date back probably to 4000 B. C., and a tablet of Entregal, King of Lagash, 3100 B. C., records "so many manas of bronze" paid for some land, but the "bronze" may have been only copper. In Egypt, the bronze red from Medun dates back to 3700 B. C., and the metal statue of Pepe I, VIth Dynasty, of hammered plates shows great knowledge of the metal worker's art. Venerable China has a claim that in the Shang Dynasty, 1783 B. C., bronze working had reached an advanced stage. Since southern China produced copper and tin in abundance and the opportunity for experimenting was good, the claim of China may be considered admissible. Egyptian tablets, however, record expeditions sent by their early kings to Sinai to obtain copper from the mines there, and tin was doubtless obtained from the Phoenician traders, who brought it from the British Isles, where it was mined 3000 years ago, and exchanged it for Egyptian products. The ancient Assyrians obtained copper from Arabia and Cyprus and tin from India and Spain, and it is quite possible that the ancient metallurgists mixed these two metals in certain proportions to obtain their alloys, although in some cases the ores themselves may have been melted together giving bronzes differing in their composition. Certain inferences may be drawn from these analyses of bronze. Egyptian bronze showed a varying composition. Where a hard cutting edge was not required lead was substituted for tin; a moderate amount of tin was used where stiffness was needed and in cast bronze where a sharp impression was necessary. Arsenic and antimony, found in certain bronze, may have had a hardening effect and possibly represents accidental impurities in the copper ores. The lead present in some Egyptian bronze may have come from the lead mines near Laurium on the eastern coast of Greece and no doubt was substituted for the tin for economy. The Egyptians, having copper, tin and lead, could have experimented with these metals in order to obtain the best proportions for different purposes. Greek "bronze," where no special qualities were required, proved to be nearly pure copper, while in samples of real bronze the addition of tin suggests that the metallurgists knew of its importance and used it for certain purposes. The bronze from Carthage contained a rather excessive amount of tin, possibly to obtain the best cast results, and as the Phoenicians dealt in tin they had plenty of that metal. The Russian alloy of copper was not a bronze but an alloy of copper and iron, and suggested that the use of tin was unknown, or the tin very difficult to obtain; the presence of iron may have had a hardening effect which a sickle with a cutting edge would have required. The bronze celt from England suggested that, at this early period, the workers in metal may have obtained copper and tin from Cornwall and discovered the best proportions to use in making their tools and weapons. The Korean bronze seems to have been an intentional alloy of copper and tin, and the spoon showed knowledge of the metallurgist's art. The Japanese and Chinese bronze mirrors showed a certain similarity of composition: the Chinese being more ancient workers in bronze than the Japanese the latter may have imitated their proportions. The Etruscan bronze shows a familiarity with the composition of a true bronze and the Etruscans must have been extensive workers in metals from the large quantity of bronze ornaments, utensils and other objects now exhibited in the Museum at Florence.

Neither North America nor Central America seems to have had a bronze age; objects of metal found of ancient date were of native copper obtained from mines of the north and northwest and hammered into shape.

The following analyses give the composition of specimens of bronze collected by the writer in the various countries visited, with a brief description of the objects. When only a small piece of the metal could be obtained, the use to which the bronze was put was judged from its general appearance.

ANCIENT EGYPTIAN BRONZE

No. 1. Bronze nail obtained from Dr. Flinders Petrie, discovered in his excavations at Old Memphis, Egypt, among ruins of the Palace of Apries, 26th Dynasty. The nail, which showed but little oxidation on the surface, was 1¾ inches long, tapering from ½ inch to ¼ inch in thickness, with rounded point and no head, composition as follows:

	per cent
Copper	74.62
Tin	.88
Lead	21.32
Iron	.34
	97.16

This nail was not a true bronze, containing, as it did, only a small amount of tin, but what was called "pot metal," an alloy of copper and lead used in prehistoric times for small objects and filling weights, and it is rather surprising to find this alloy in a nail, where some rigidity was required.

The accompanying microphotograph (Fig. 7) shows the alloy of copper to be supersaturated with lead. The dark portions are lead and the lighter ones the copper alloy.

No. 2. Specimen of bronze obtained by Dr. Petrie in his excavations at the Palace of Apries, 26th Dynasty. A fragment of cast bronze, flat piece ⅝ inch thick.

Composition

	per cent
Copper	92.00
Tin	6.52
Lead	.82
Iron	.28
	99.62

A true bronze with minimum amount of tin. Lead and iron were probably impurities in the ore.

No. 3. Obtained from a reliable curio dealer in Egypt who stated the specimen was found in the Pyramid of Illahun on the Fayum, 12th Dynasty.

Cast hollow handle, possibly a utensil or weapon.

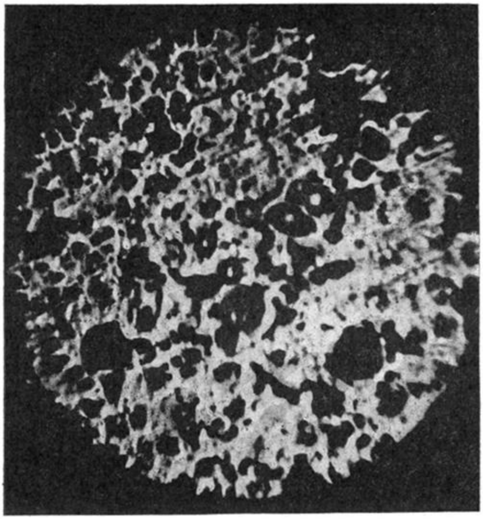


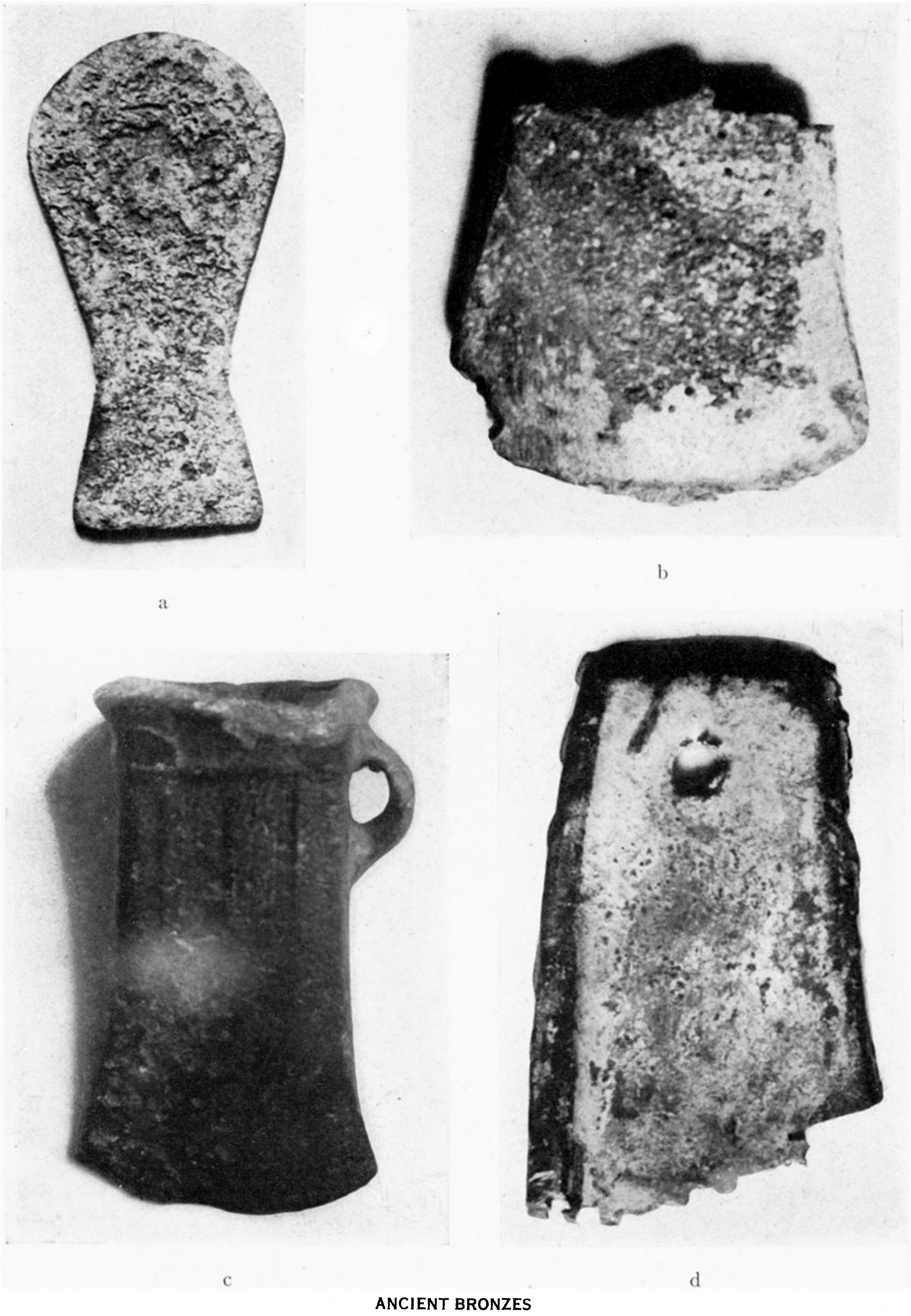
FIG. 7.—Microphotograph of "bronze" nail from the palace of Apries, Old Memphis, Egypt, containing an alloy of copper and lead; enlarged 75 diameters. (No. 1.)

Composition

	per cent
Copper	73.66
Tin	4.78
Lead	19.25
Cobalt	.81
Iron	.19
	98.69

This alloy showed an economy in tin and a large proportion of lead. The cobalt and iron were doubtless impurities in the ore.

No. 4. Obtained from Mohassib, a well informed curio dealer at Luxor. The specimen (Pl. I, a) was a small paddle shaped tool 2¾ inches long and ⅛ inch thick, found at Thebes near the Ramesseum, 12th Dynasty. Surface oxidized.



a b c d

ANCIENT BRONZES

a. Egyptian bronze from Thebes (No. 4 in text); b. Greek bronze ax head from Taormina, Sicily (No. 10 in text); c. Bronze celt from Pickering, England (No. 16 in text); d. Russian "bronze" handle of sickle (No. 15 in text).

Composition	per cent
Copper	88.95
Tin	.16
Antimony	.68
Arsenic	5.60
Lead	.65
Tin	.32
	96.36

This alloy was deficient in tin. Hardness was insured by the presence of antimony and arsenic which occur in copper ores from Cornwall, Saxony, and other localities.

No. 5. The fragment of a bronze bowl from Luxor, 11th Dynasty, obtained from the Museum in Cairo.

Composition	per cent
Copper	85.83
Tin	3.51
Lead	8.50
Iron	.24
	98.08

In this alloy there is an economy in tin and a substitution of lead. The thinness of the metal suggested it had been hammered out.

GREEK BRONZE

No. 6. This specimen was obtained from Dr. Stais, Director of the Museum at Athens, Greece. It was thin sheet metal probably from a bowl or vessel from Dr. Schliemann's tombs at Mycenae, date 1500 B. C.

Composition	per cent
Copper	99.38
Lead	.17
Arsenic	.19
	99.74

Almost pure copper; lead and arsenic impurities in the ore.

No. 7. A specimen of Greek bronze; same source and date as the above. Metal ⅛ inch thick, enclosed in an outer coating of metal—possibly a sword handle.

Composition	per cent
Copper	99.37
Tin	.10
	99.47

Nearly pure copper, the small amount of tin probably an accidental impurity.

No. 8. A fragment of Greek bronze from the Acropolis of Athens, date 520 B. C., obtained from the Museum. Cast metal, thick and of irregular shape.

Composition	per cent
Copper	88.07
Tin	9.66
Lead	.30
	98.03

True bronze, the tin present giving hardness suitable for tools or other purposes.

No. 9. Thin plate, probably a utensil, obtained from Dr. Stais of the Athens Museum, Schliemann's tombs, Mycenae.

Composition	per cent
Copper	95.63
Tin	.07
Iron	.87
Phosphorus	.14
	96.71

This metal, found with the bones of a burial, may have combined with the phosphorus in the bones causing an accidental impurity.

No. 10, Greek Bronze from Taormina. Portion of an ax head (Pl. I, b), said to date from about 600 B. C. Wedge shaped piece ½ inch thick at back where broken off, cutting edge 3 inches across the face, which was somewhat broken and worn; the surface was pitted and covered with a layer of green carbonate of copper.

Composition	per cent
Copper	90.28
Tin	7.31
Lead	.19
Zinc	.17
Iron	.48
	98.43

This specimen seemed to be a real bronze, although the presence of zinc in the alloy is unusual. Having been purchased at a curio shop, the authenticity is somewhat doubtful.

No. 11, Silver Alloy from Greece. A piece of thin silver, portion of a vase or ornament from Schliemann's tombs at Mycenae, obtained from Dr. Stais of the Athens Museum. It was covered with a scale which was detached and analyzed separately.

Composition of the Clean Metal	per cent
Silver	95.88
Copper	3.48
Gold	.43
	99.79

No. 12, Scale on Silver Alloy from Greece.

Composition of the Scale	per cent
Silver Chloride	42.80
Silver Oxide	44.80
Copper Oxide	10.40
Gold	.40
Moisture	1.60
	100.00

The composition of this alloy was remarkable from the fact that it might have contained more copper without affecting its brilliancy, and the presence of sufficient gold to have made it profitable to have separated the gold from the silver had these ancient metal workers known how to "part it." This composition suggests that they may have obtained the alloy from smelting some ores containing these metals without knowing much about the composition.

PHOENICIAN BRONZE

No. 13. A bronze mirror obtained at the Museum at Carthage, round, 3¾ inches in diameter, with no handle, differing in this respect from the Roman mirrors found at Carthage. Age uncertain, but the fact that it was greatly corroded, covered with a brown oxidation, and very brittle, suggests it might have come from the Old Punic Cemetery, the Necropolis of St. Louis, dating from about the 5th Century B. C.

Composition

	per cent
Copper	82.00
Tin	14.36
Iron	.63
	96.99

Owing to the oxidation it was not possible to obtain a sample of clean metal for analysis. The proportion of tin shows an unnecessary amount of this metal.

BRONZE FROM CEYLON

No. 14. A bronze begging bowl given the writer by Dr. Joseph Pearson, Director of the Colombo Museum, unearthed at Polonnaruwa, Central Province of Ceylon, and believed to belong to the 12th Century, A. D. It was 6 inches in diameter, the bottom entirely gone; the rim was about 1/16 to ⅛ inch thick and had the appearance of being cast.

Composition

	per cent
Copper	77.46
Tin	19.63
Lead	.19
Cobalt	.43
	97.71

The large amount of tin may have been given for hardness and durability; the lead and cobalt are doubtless impurities.

RUSSIAN BRONZE

No. 15. When at Moscow, a bronze sickle was taken from a case in the Imperial Museum by the Director, Prince N. Steherbatoff, and given to the writer for analysis. It was only the handle, the blade having been broken off, and was of the Siberian type from the government of Saratow, central Russia, the date being 1500 to 1700 B. C. The handle was 3 inches long, from 1¾ to 2¼ inches wide, and ⅛ inch thick, reinforced with a stout iron rim on one side, and was evidently cast (Pl. I, d).

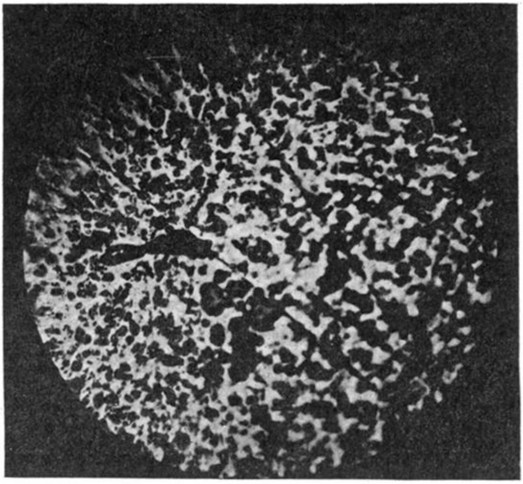


FIG. 8.—Microphotograph of Russian "bronze" sickle containing an alloy of copper and iron; enlarged 75 diameters. (No. 15.)

Composition	per cent
Copper	91.55
Iron	6.22
Cobalt	.30
	98.07

This alloy is remarkable from the fact that it contained no tin and a larger amount of iron than is found as an impurity in alloys, suggesting that the copper may have been reduced from a mixture of copper ores containing considerable iron.

The accompanying microphotograph (Fig. 8) shows the peculiar structure of this alloy.

BRONZE CELT FROM ENGLAND

No. 16. James M. Mitchelson, Esquire, of Pickering, England, unearthed, in a round barrow in the hills above the Vale of Pickering, many prehistoric relics, stone implements, incense cups, food vessels, etc., and roughly cast bronze celts, which he assigned to the early bronze period, 1800 to 1500 B. C. He was kind enough to give the writer one of these celts from his private museum for analysis.

Socketed celt, with square socket, a loop on one side but no ornamentation (Pl. I, c).

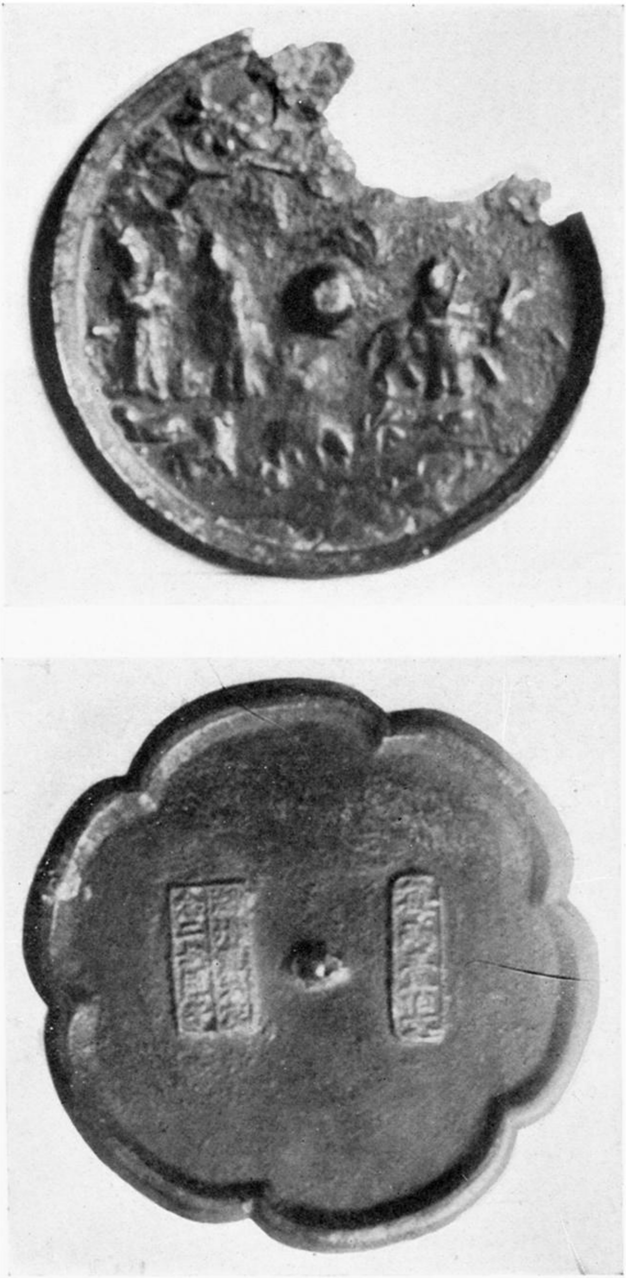
Composition	per cent
Copper	83.80
Tin	10.18
Lead	5.31
Iron	.41
	99.70

KOREAN BRONZE

No. 17. From the museum at Seoul, Korea, a bronze spoon was obtained, said to have come from an ancient grave at Songdo, date 900 to 1400 A. D. It was well shaped, with a curved handle like a soup ladle, and was stiff and rigid. The metal was coated with a thin patina of a pale green color, and when cleaned had a whitish red appearance.

Composition	per cent
Copper	77.25
Tin	21.54
Lead	.02
Iron	.70
	99.51

The amount of tin in this alloy seems excessive but was probably used to secure hardness and rigidity. Copper was mined at Kapsan, Korea, and was smelted in a "hole in the ground process" until recent times.



ANCIENT BRONZES

Above Japanese bronze mirror of the Ashi Kaga period (No. 18 in text); below Chinese bronze mirror of the period of the Ming Dynasty (No. 19 in text).

JAPANESE BRONZE

No. 18. Mirror bought at Kyoto from a reputable curio dealer, who stated the mirror was of the Ashi Kaga period, and about 600 years old, and that it had been in a fire. The mirror had a crude appearance, with no evidence of a polished surface, the back having rough figures of men and animals raised in high relief above the cast surface. (Pl. II, upper figure.)

Composition	per cent
Copper	73.20
Tin	10.80
Lead	14.50
	98.50

The per cent of tin is the usual amount in true bronze; why the large amount of lead is unknown.

CHINESE BRONZE

No. 19. Mirror (Pl. II, lower figure) obtained at Canton and probably of the Ming Dynasty (1368–1643). The mirror had three columns of Chinese letters on the back. The reflecting surface had been polished and had a white coating, much worn away; it was examined for silver but proved to be tin. The mirror had no handle, but an ornamental edge.

Composition	per cent
Copper	65.20
Tin	9.72
Lead	23.19
	98.11

No. 20. The figure of a little elephant of rather crude workmanship, from Peking, said to have come from a temple, date uncertain, but said to be 200 years old.

Composition	per cent
Copper	56.60
Tin	.62
Lead	5.73
Zinc	31.99
Iron	4.47
	99.41

This alloy, containing but a very small quantity of tin and nearly 32 per cent of zinc, was not bronze but an ordinary brass.

BRONZE FROM ETRURIA

No. 21. A specimen of ancient bronze was obtained at Florence from the Director of the Etruscan Museum, Barlozzetti Cesare, R° Museo Archeologico Firenze, found in one of the tombs at Populonia Piombino, date 3rd or 4th Century B. C.

The metal was very thin, evidently beaten out, and was probably some portion of a vessel or utensil.

Composition

	per cent
Copper	84.28
Tin	10.28
Lead	None
Zinc	None
Iron	None
Phosphorus	Trace
	94.56

Owing to the specimen being very thin and covered with a green scale, it was impossible to get a fair sample. Clean metal would probably have shown a true bronze with 90 per cent copper and 10 per cent tin. The absence of any trace of iron is rather unusual in ancient bronze. The presence of a trace of phosphorus in the bronze may be accounted for when associated with an ancient burial.

BRONZE FROM YUCATAN

No. 22. A small globular-shaped bell about 5/8 inch in diameter and 3/4 inch long found with a number of others in a jar with inscribed characters buried in a mound near the village of Humebchin, Yucatan, yielded on analysis:

	per cent
Copper	97.00
Tin	.34
Lead	1.00
Iron	.07
	98.41

Of course this was not a true bronze; the small amount of tin, lead, and iron may be regarded as impurities in the ore. Central America, in spite of the advanced civilization of the Maya race, does not seem to have reached the Bronze Age.

BRONZE FROM CRETE

No. 23. A small fragment of bronze from Crete, so badly oxidized that no clean metal could be obtained, gave an analysis:

	per cent
Copper	68.44
Tin	13.47
Iron	.05
Lead	Trace
	81.96

The results obtained simply showed the use of tin in generous proportions in the bronze alloy.

TIBETAN BRONZE

No. 24. A curious mask-like bronze head obtained at Darjeeling, said to have come from Tibet, of no particular date. It was about four inches across the face, and had a wide-open, capacious mouth, for the purpose of preserving the ashes of a Lama, or priest. The addition of horns on the head and strange ornamentations gave it a grotesque appearance.

Composition

	per cent
Copper	83.78
Zinc	15.00
Iron	1.30
Tin	None
	100.08

As this alloy contained no tin, it could not be considered a bronze, but rather an ordinary brass, and probably quite modern.

The specimen, while it claimed no interest as an alloy of copper and tin, or bronze, displayed considerable skill in the casting, and seems to have been treated so as to give it the reddish-brown appearance of a "bronze." The clean metal itself had the reddish look of a copper and tin alloy, and not the yellow tint of a copper and zinc brass.

BRONZE FROM SOUTH AMERICA

Objects in metal of ancient manufacture in Peru show that some portions of South America at least passed through a "Bronze Age." Specimens of prehistoric bronze from Machu Picchu when analyzed gave interesting results. The analysis in a paper by Dr. C. H. Mathewson gives the following composition in percentages:

	Copper	Tin	Iron	Zinc
A. Knife	94.26	4.82	0.28	.....
B. "	96.79	3.00	None	.....
C. "	95.35	4.22	None	.....
D. "	96.79	3.00	None	.....
Chisel	96.20	3.71	None	.....
Ax head	93.70	5.01	None	.....
Ornamented spatula-shaped piece	86.03	13.45	.....	0.32
Irregular-shaped piece	95.68	4.20	.....	.....
Mirror with handle	94.35	5.34	.....	.....

Mr. W. A. Wesslin's analyses of bronze from South America gave the following results:

	Tin
Knives, chisels, and ax heads requiring hardness and strength	5.00–10.00
Tools from Bolivia	2.00–10.00
Pins from Bolivia	1.00–10.00
Clamps and some other objects from Bolivia	little if any
Ornamental figures and bolos from Bolivia	nearly 10.00
Objects from Cuzco, such as knives, chisels, and ax heads	3.87– 8.53
Ornamental figures from Cuzco	1.97– 8.54
Bronze objects found in the ruins of Tiahuanaco gave	
For cutting tools	3.27– 7.79
For ornaments	1.28–10.59

(The tin in bronze cutting tools from South America seems to range from 3.00 to 8.00 per cent minimum amount, while ornamental objects contained from 8.00 to 10.00 per cent tin, a rather excessive amount.)

The Bingham expedition of 1912 in Peru found at Machu Picchu, not only many specimens of bronze tools and implements, but a large mass of pure metallic tin, showing that the Inca metallurgists were familiar with tin and knew how to obtain it by smelting the cassiterite ore found associated with copper in the lodes in Bolivia.

When native copper could be found, and tin obtained from the easily reduced cassiterite ore, it is not surprising that experiments should have been made in melting these two metals together in different proportions, and that the Incas should have discovered that a certain amount of tin produced hardness, and the best results in casting, and that a minimum amount of tin, with forging, annealing and cold working, yielded a suitable alloy for tools. This would explain a certain uniformity of composition in tools and objects which would not be obtained by smelting ores of unknown composition, yielding a metal of a varying, accidental and uncertain nature, although it is quite probable a bronze may have been obtained by smelting together ores containing both copper and tin when the metals themselves were not obtainable.

In conclusion I desire to acknowledge the valuable assistance of Dr. D. L. Wallace of the Chemical Department of the University of Pennsylvania, who aided me in my analyses and determinations of compounds in some of the ancient bronzes. The microphotographs were made at the Laboratory of Physics of the University.

PHILADELPHIA, PA.